AD-A108 496 REMINGTON ARMS CO INC BRIDGEPORT CONN F/G 19/1

TRACER SIMULATION STUDY.(U)

APR 72 W G PLATT DAAA25-71-C-0069

UNCLASSIFIED NL

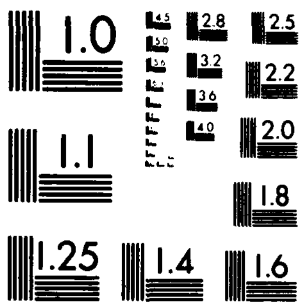
1 of 1

END

DATE FILMED

1 82

DTIC



MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU OF STANDARDS 1963 A

LEVEL

TRACER SIMULATION STUDY

Contract No. DAAA25-71-C0069

FINAL SUMMARY REPORT - PHASE I

Report Period

September 1970 Through August 1971

by

W. G. Platt

April 1972

Remington Arms Company
Bridgeport, Connecticut

for

Frankford Arsenal
Philadelphia, Penn.

TABLE OF CONTENTS

I. INTRODUCTION

This report covers the experimental work done to investigate the sensitivity of 5.56mm tracer bullets to focused infrared radiation from a carbon dioxide laser. The bullets were uncrimped and without closure discs as they would be after completion of the charging operation in production. It was hoped that the thermal sensitivity of the tracers at this stage of production could be correlated with the results obtained from firing the completed rounds in a weapon. If correlation was established, then an increased severity test based on thermal sensitivity could be used to determine the quality of a lot of tracer bullets during production. In addition, the combination of this test with the simultaneous measurement of light output from the burning tracer would be advantageous.

Initial experiments were performed with spinning tracer bullets and the effect of spin rate on burning duration observed. It was found that the laser could easily ignite tracers spinning at rates up to 90,000 rpm and that simultaneous measurement of light output and duration was not a problem. This phase of the testing was abandoned because the spinner acceleration and deceleration times severely limited the rate of testing, and also since ignition has been reported to occur during the first inch of bullet travel,[1] there is no need to spin the bullet when only the ignition phase is being investigated. All subsequent testing was done with the bullets at rest. Ignition and burning took place in free air without confinement and while this is a radical departure from the environment in a gun chamber it was a necessary simplification for this series of experiments. Simulation and control of the firing environment in a gun chamber is a more difficult, but possibly a necessary step in establishing the desired increased severity test.

Power, power density, and duration of the applied stimulating radiation were the controlled variables for the static ignition tests. Measurements were made of the ignition time, and from this the ignition energy was calculated for a known laser power. Ignition was said to have been attained when the exothermic reaction of the tracer mixture continued after cut off of the stimulus irrespective of the attainment of a complete burning cycle. Ignition energy measurements, it was hoped, would provide a quantitative measure of the differences between lots of tracer ammunition independent of the subsequent burning performance.

The first sample lots submitted for testing differed very little in weapon performance (100, 98, 96% Fire), and all were considered to be of acceptable quality. No significant difference in their sensitivity to the laser radiation was found by experiment. However, the tests did establish the stimulus needed to obtain a desired level of response. Subsequent lots with weapon performance levels of 100, 86, 62 and 50% provided differences that were significant, and their test results constitute the basis for the conclusions formed and stated by this report.

Considering the complexity and the number of variables involved in the final stage of tracer bullet manufacture, the additional variables introduced in a weapon firing test, and the effects of long term storage on performance, the correlation of the laser test with weapon firing would be an extremely fortuitous result. That such is not the case for this phase of the experimentation is evident from the results presented in this report.

II. SUMMARY

Although an ordered and consistent difference in the sensitivity of 5.56mm tracer bullet lots to focused infrared laser radiation was established by experiment, the differences do not correlate with those found by weapon testing. The lot most sensitive to the laser stimulus is the worst performer in weapon firing, but this inverse relationship is not maintained over the range of sensitivities investigated. The best performing lot in a weapon is not the lot least sensitive to the laser stimulus. This result indicates for the test conditions described in this report, that the thermal sensitivity of 5.56mm tracer bullets to focused infrared laser radiation is not a useful measure of their subsequent weapon performance particularly since a partially inverted relationship is evident in the test results.

Previous work by T. Stevenson of Pitman-Dunn Labs, Frankford Arsenal,[2] established that the pyrotechnic compositions used in tracer bullets are sensitive to impact and that tracer ignition is probably a function of both thermal and impact sensitivity. This suggests a series of experiments that might be performed to combine laser ignition with varying degrees of confinement of the tracer bullet and moderate initial static pressures of up to 2000 psi. A pressure close to this level is generated

by the firing of the 5.56mm primer and it could be that the primer energy is one of the more important factors involved in the ignition of tracers. Stevenson's report[3] of a 12% firing level for .30 caliber tracer bullets with zero barrel length and a 100% level for one inch of barrel indicates that a self-sustaining exothermic reaction is generated very early in the weapon firing cycle.

Ignition energy measurements were not conclusive, but they did indicate rather strongly and consistently that the lot requiring the least energy to obtain ignition also performed worst in a weapon, and this was true for all tests. When the surface quality or condition of the lots was tested by making reflectance measurements with a helium-neon laser, the worst lot for weapon performance proved to be the most reflective. Conversely, the same anomaly that was true for the laser ignition performance and for ignition energy was also true for the reflectance measurement; the best weapon performance lot was not the least reflective.

The use of the laser for igniting spinning tracer bullets is a practical application of this unique energy source. The ability to control and measure the radiant energy delivery to the spinning tracer and to accomplish this energy transfer efficiently and without mechanical contact are attributes of a laser system that qualify it for this application.

III. TEST RESULTS

1. Laser Ignition and Measurement of Burning Characteristics at High Spin Rates

Previous work on ignition of spinning tracer bullets by an air-drive lightweight firing pin method[2] indicated the difficulties involved in performing this operation. Other methods using the output of hot gases from a primer or the directed flame from a bunsen burner were also discussed in this referenced report. The difficulties presented by this operation serve to emphasize the advantages of using a laser system. It can control and measure the magnitude, intensity, and duration of the energy input to the tracer sample and direct this energy to the spinning tracer target without making mechanical contact. Table I lists laser powers, pulse duration, and calculated energies for the three spin rates that were tried.

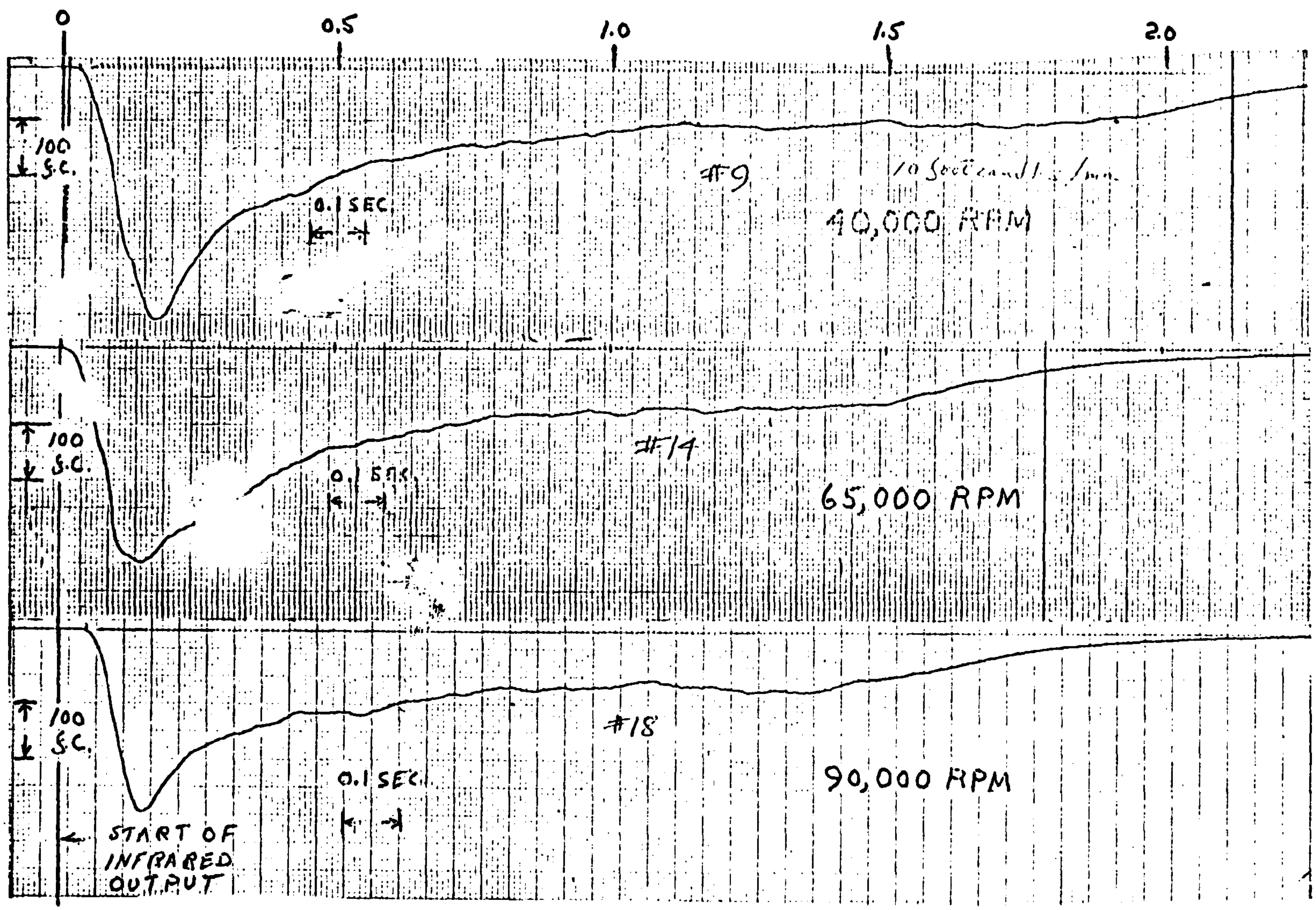
No attempt was made to determine differences in ignition energies between lots or to test the sensitivity on a burn or no-burn basis. Laser energy delivery was set high enough to insure that good ignition and burning was obtained. The light output curves at rotation rates of 90, 60, and 45 thousand rpm are shown in Figures 1, 2, and 3 for the first lots of tracers sent to Remington for testing. All lots had acceptable levels

TABLE I

5.56mm TRACER - LASER IGNITION AT HIGH SPIN RATES

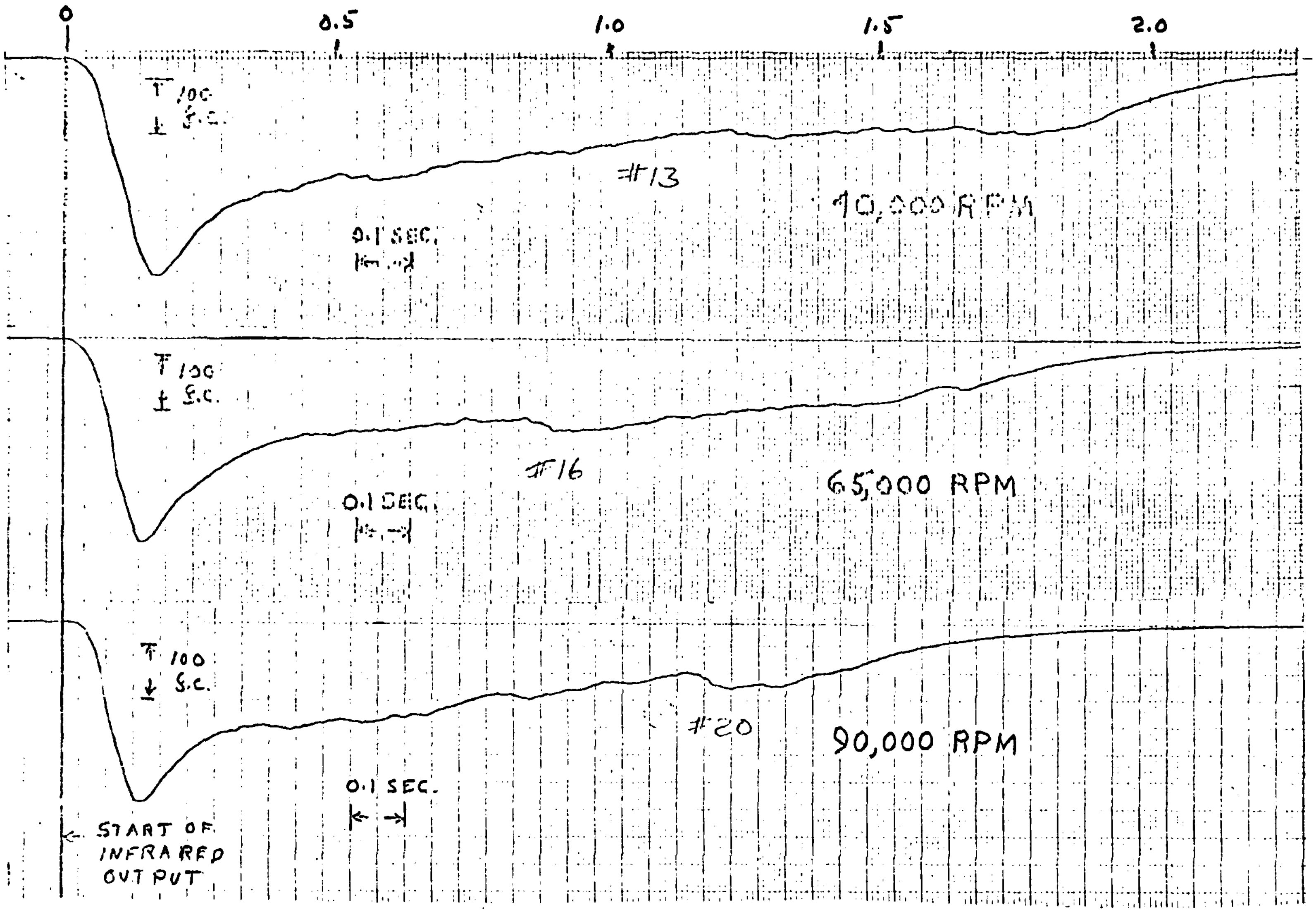
Sample	Laser Power (Watts)	Pulse Length (milliseconds)	Pulse Energy (joules)	RPM X1000	Burning Time (seconds)
100% Fire	43.5	25.8	1.12	40	2.09
Contract	40	28.8	1.15	40	2.12
#395	40	30.3	1.21	65	1.79
	42.5	32.0	1.36	90	1.74
	45	32.0	1.44	90	1.83
98% Fire	39	28.6	1.12	40	2.00
Contract	45	29.0	1.30	40	1.86
#394	42	31.0	1.30	65	1.78
	43	32.5	1.40	90	1.62
96% Fire	39	29.2	1.14	40	1.95
Contract	40	31.0	1.24	65	1.78
#393	44	32.5	1.43	90	1.78

(No ignition failures. All values are for individual samples.)



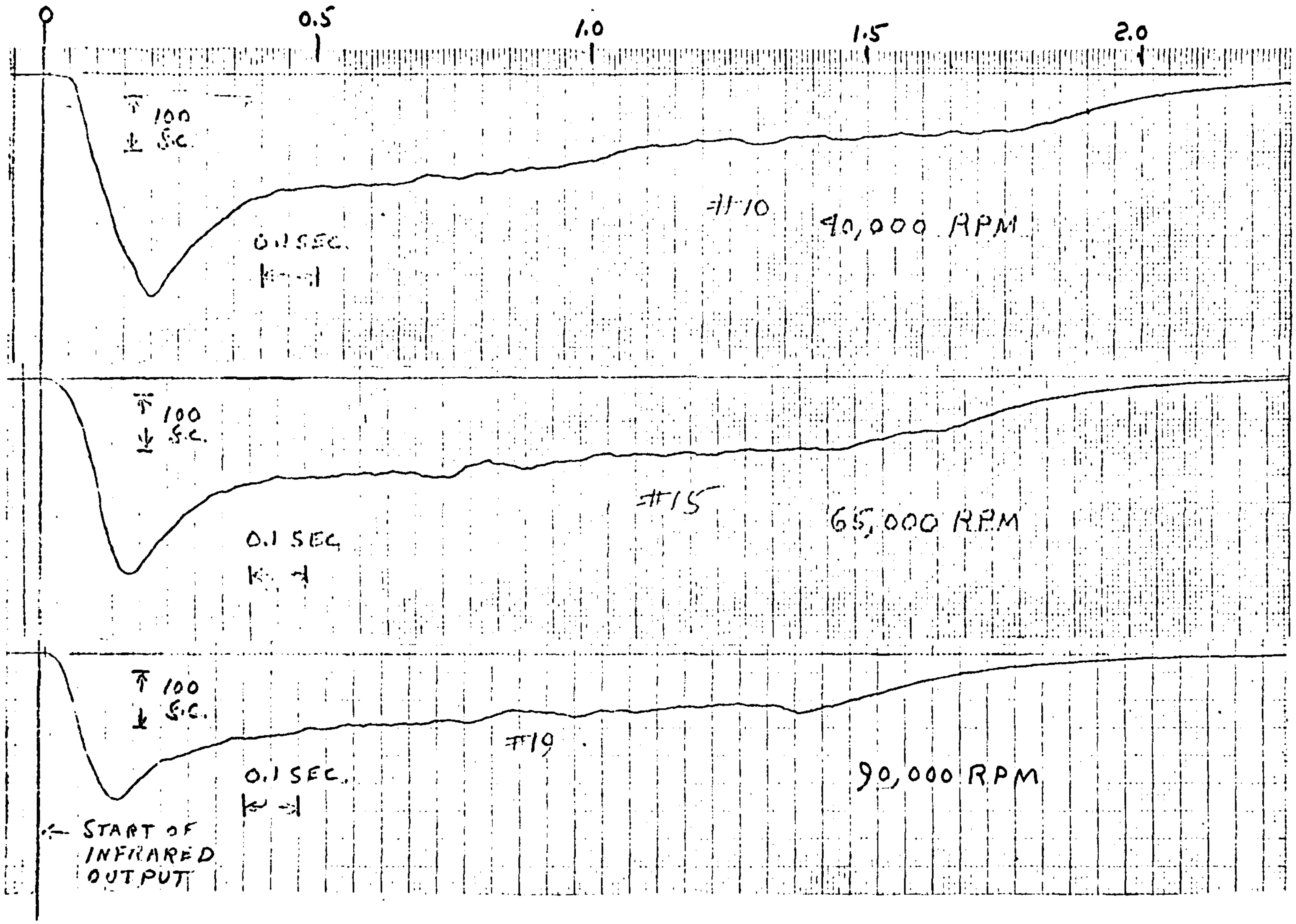
LIGHT OUTPUT FROM SPINNING TRACER - 100% FIRE

FIG. 1



LIGHT OUTPUT FROM SPINNING TRACER - 98% FIRE

FIG. 2



LIGHT OUTPUT FROM SPINNING TRACER - 96% FIRE

FIG. 3

of weapon performance, 100, 98 and 96%. There is a reduction in light output for all three lots with increasing rpm and also a reduction in burning time. No significant difference between samples is evident. Determination of total light output by graphical integration of areas under the curves was not attempted because the slow response of the photometer seriously limited the accuracy obtainable. Due to the time necessary for accelerating and decelerating the spinner and also because the spin may affect the ignition process, this portion of the experimental program was discontinued. Combination of a spin test with an increased severity test in the future is not ruled out by this action if the time is not excessive and if experimentation indicates that high spin rates do not affect the initial igniting process.

2. Ignition Tests

A. (Lots with 100, 98, and 96% weapon firing performance)

Very little difference in the weapon firing performance of the samples lots was evident, a fact also borne out by a statistical analysis of the laser ignition tests. On the basis of the energy required to ignite the tracers, all tests failed to reject the null hypothesis, (no difference between sample means) at a confidence level of 90% using the F-ratio test. The data were tested to see that they met the requirements for using the F-ratio test and normality of distribution confirmed by using the Kolmogorov-Smirnov non-parametric test.

Results for the individual sample lots are given in Table II. The number of bullets used per test was small due to the limited sample size available and also because it was necessary to establish the range of stimulus levels needed before increasing the number of shots fired per sample.

A tabulation of the results from combined lots is given in Table III, and a graphical presentation in Figure 4. The dependence of ignition and burning on the total energy supplied is evident and also the dependence of ignition time on power density. Spot size was kept the same (0.090" diameter) for all the tests and in general it is evident that the higher laser powers produced shorter ignition times and energies. Failure to detect significant differences in sample lots on the basis of ignition energy was not surprising for this test series in view of the narrow range of sample sensitivities involved. It indicated the limited resolution obtainable by measurement of this parameter. Differences in the sensitivity of the sample lots, based on the fraction that ignited and burned, did not indicate an ordered and consistent sensitivity to the laser radiation.

TABLE II

5.56mm Tracer Bullets - Individual Lots (100, 98, 96% Fire)

Sample	Pulse Energy Millisecs.	Fraction Ignited & Burned	Ignition Energy Millijoules	Ignition Time Millisecs.	Laser Power Watts	Pulse Length Millisecs.	Ignition Energy Std. Dev.	Ign. Energy Coeff. of Variation	No. of Shots
100	880	1.0	177	4.0	44.2	19.9	81.3	46.0	5
98	863	1.0	263	6.1	43.2	20.0	87.2	33.2	5
96	885	1.0	220	4.0	43.9	19.9	82.8	37.7	5
100	766	1.0	334	9.5	35.0	21.9	52.7	17.3	5
98	766	1.0	283	8.1	34.9	21.9	70.0	24.7	5
96	752	1.0	356	10.3	34.6	21.7	83.7	23.5	5
100	715	0.8	368	10.5	35.0	20.4	100.3	27.2	4
98	710	1.0	441	12.7	34.8	20.4	96.0	21.2	5
96	713	1.0	344	9.1	34.9	20.4	46.6	13.5	5
100	685	0.2	391	11.4	34.4	19.9	Insufficient Data		5
98	688	0.8	344	10.0	34.4	20.0			5
96	686	0.6	347	10.6	34.3	20.0			5
100	622	0.7	356	9.0	39.6	15.7	79.2	22.2	10
98	628	0.7	440	11.0	40.0	15.7	100.1	22.7	10
96	621	0.5	408	10.2	39.8	15.6	86.5	22.1	10
100	564	0.4	272	6.1	44.6	12.7	113.4	41.7	15
98	566	0.53	333	7.5	44.8	12.7	102.9	30.9	15
96	566	0.73	290	6.4	44.9	12.6	87.4	30.1	14
100	505	0.4	227	5.4	42.3	11.9	62.3	27.5	15
98	505	0.47	206	4.9	42.8	11.9	68.1	33.1	15
96	504	0.4	232	5.4	42.2	11.9	79.9	34.1	14

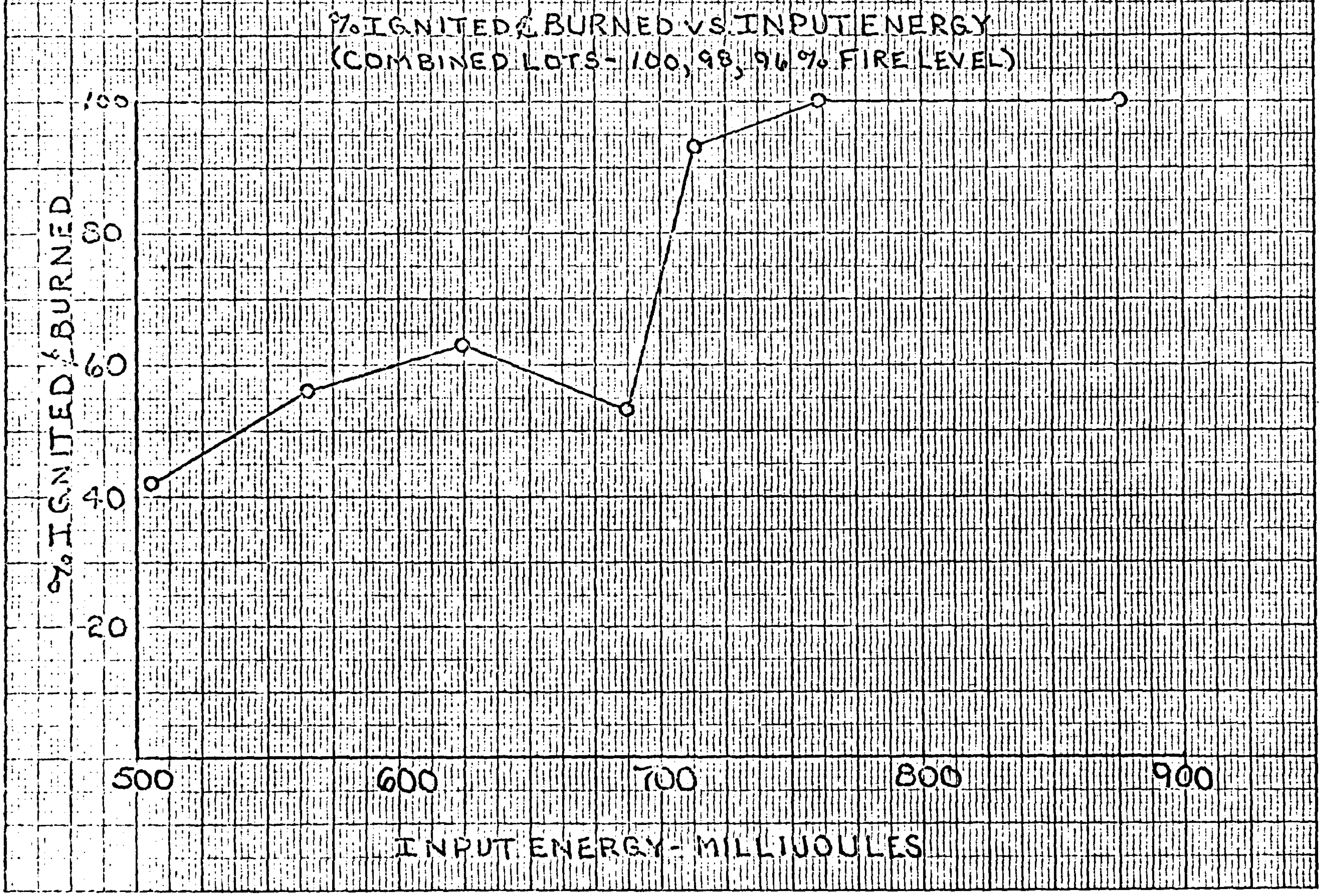
TABLE III

5.56mm Tracer Bullets - Combined Lots (100, 98, 96% Fire)

Input Energy Millijoules	Fraction Ignited & Burned	Ignition Energy Millijoules	Ignition Time Millisecs.	Laser Power Watts	Pulse Length Millisecs.	Ignition Energy Std. Dev.	Ign. Energy Coeff. of Variation	No. of Shots
876	1.0	220	4.7	43.8	20.0	85.9	39.0	15
761	1.0	325	9.3	34.8	21.8	72.0	22.2	15
713	.93	279	10.7	34.9	20.4	89.0	23.5	14
686	.53	358	10.7	34.4	20.0	99.1	27.6	15
624	.63	402	10.1	39.8	15.7	92.9	23.1	30
565	.56	298	6.7	44.7	12.7	103.1	34.6	44
505	.42	222	5.2	42.4	11.9	69.6	31.4	44

K+E 10 X 10 TO ½ INCH 46 1320
7 X 10 INCHES MADE IN U.S.A.
KEUFFEL & ESSER CO.

FIGURE 4



B. Lots with 100, 86, 62 and 50% Weapon Firing Performance

The following sample lots were tested:

Code No.	Weapon Performance	Reported Defects
108	100% fired	
109	85% fired	1 short - 6 blinds
110	62% fired	3 delays - 2 shorts - 14 blinds
Control	50% fired	not given

Laser ignition energy measurements, it was hoped, would provide a quantitative determination of the quality of a lot of tracer bullets that would correlate with their weapon firing test results. Ignition energy is the product of laser power and ignition time as measured from initiation of the laser stimulus to the first detectable radiant emission. It includes corrections made for differences in reflectance between sample lots. Ignition is said to have occurred if light emission from the tracer continues after cut-off of the laser radiation irrespective of completion of the burning action. Many partial ignitions are included in the ignition energy calculations since burning failed to continue after ignition. Test results tabulated in order of decreasing input energy are given in Table IV. Test #5 approached the zero ignition and burn level so that comparison of results on a statistical basis for ignition energies was not possible.

TABLE IV

5.56mm Tracer Bullets - 100, 86, 62 & 50% Fire

Test No.	Sample	Input Energy* Millijoules	Percent Ignited & Burned	Ignition Energy* Millijoules	Ignition Time Millisecs.	Laser Power Watts	Pulse Length Millisecs.	Ignition Energy* Std. Dev.	Ign. Energy Coeff. of Variation	No. of Shots *
1	86	654	60	414	12.8	35.6	20.0	91	22	5 - 5
	100	641	100	398	12.4	35.6	20.0	166	41	5 - 4
	62	632	100	332	10.5	35.5	20.0	105	32	5 - 5
	50	628	100	299	9.5	35.3	20.0	115	38	5 - 5
2	86	587	20	468	12.1	42.4	15.1	74	16	10 - 9
	100	573	70	451	11.8	42.1	15.1	104	23	10 - 8
	62	567	80	413	11.0	42.0	15.1	52	12	10 - 9
	50	555	100	348	9.6	41.2	15.2	49	14	10 -10
3	86	547	0	330	7.6	47.2	12.6	116	35	10 - 6
	100	534	40	358	7.4	47.0	12.6	110	31	10 - 8
	62	527	70	343	8.2	46.8	12.6	113	33	10 - 8
	50	537	80	330	7.9	47.1	12.6	81	24	10 - 9
4	86	535	60	315	14.9	23.0	25.4	86	27	10 - 8
	100	527	70	281	13.5	23.1	25.4	81	29	10 -10
	62	522	80	264	12.8	23.1	25.3	60	23	10 - 9
	50	516	90	218	10.7	22.9	25.3	46	21	10 - 9
5	86	476	20	420	13.5	35.2	15.0	Insufficient Data		5 - 5
	100	475	0	475	18.6	35.3	15.0	Delayed Ignitions		5 - 2
	62	470	0	436	14.8	35.1	15.0	on all samples		5 - 4
	50	470	20	415	14.2	35.1	15.0			5 - 5

*NOTE: All energies are corrected for losses by reflection.
**NOTE: Number of ignition energy determinations.

The following observations are pertinent to the test results given in Table IV:

1. An ordered and consistent sensitivity to focused laser radiation was found that does not correlate with weapon testing. An inverse relationship is indicated except for the anomaly due to the relative order of the 86% and 100% weapon fired lots. Combining of the 100 and 86% lots as acceptable, and the 62% and 50% as rejectable emphasizes this inverse relationship as shown in Table V.
2. Only two tests, #2 and #4, showed differences in sample ignition energies that could be verified statistically at a confidence level of 0.90. The large standard deviations that occurred on all tests do not provide confidence in this parameter as a measure of lot quality.
3. The ability to generate a self-sustaining deflagration is related to the size and temperature of the hot spot created at the surface of the tracer mixture. The focused spot size was kept constant (0.1" diameter) so that power density at the sample surface was proportional to laser power. Duration and power of the laser stimulus was controlled and varied in

TABLE V

Combined Acceptable Lots (100 & 86% Fire) Vs. Rejectable Lots (62 & 50% Fire)

Test No.	Weapon Performance	Pulse Energy* Millijoules	Percent Ignited & Burned	Ignition Energy* Millijoules	Ignition Time Millisecs.	Pulse Length Millisecs.	Laser Power Watts	Coeff. of Variation
1	Accept	648	80	406	12.6	20.0	35.6	32
	Reject	635	100	316	10.0	20.0	35.4	35
2	Accept	580	45	460	11.0	15.1	42.0	20
	Reject	561	90	380	10.3	15.2	41.6	13
3	Accept	540	20	344	7.5	12.6	47.1	33
	Reject	532	75	336	8.0	12.6	47.0	28
4	Accept	531	65	298	14.2	25.4	23.0	28
	Reject	519	85	241	11.8	25.3	23.0	22
5	Accept	476	10	448	16.0	15.0	35.2	
	Reject	470	10	426	14.5	15.0	35.1	

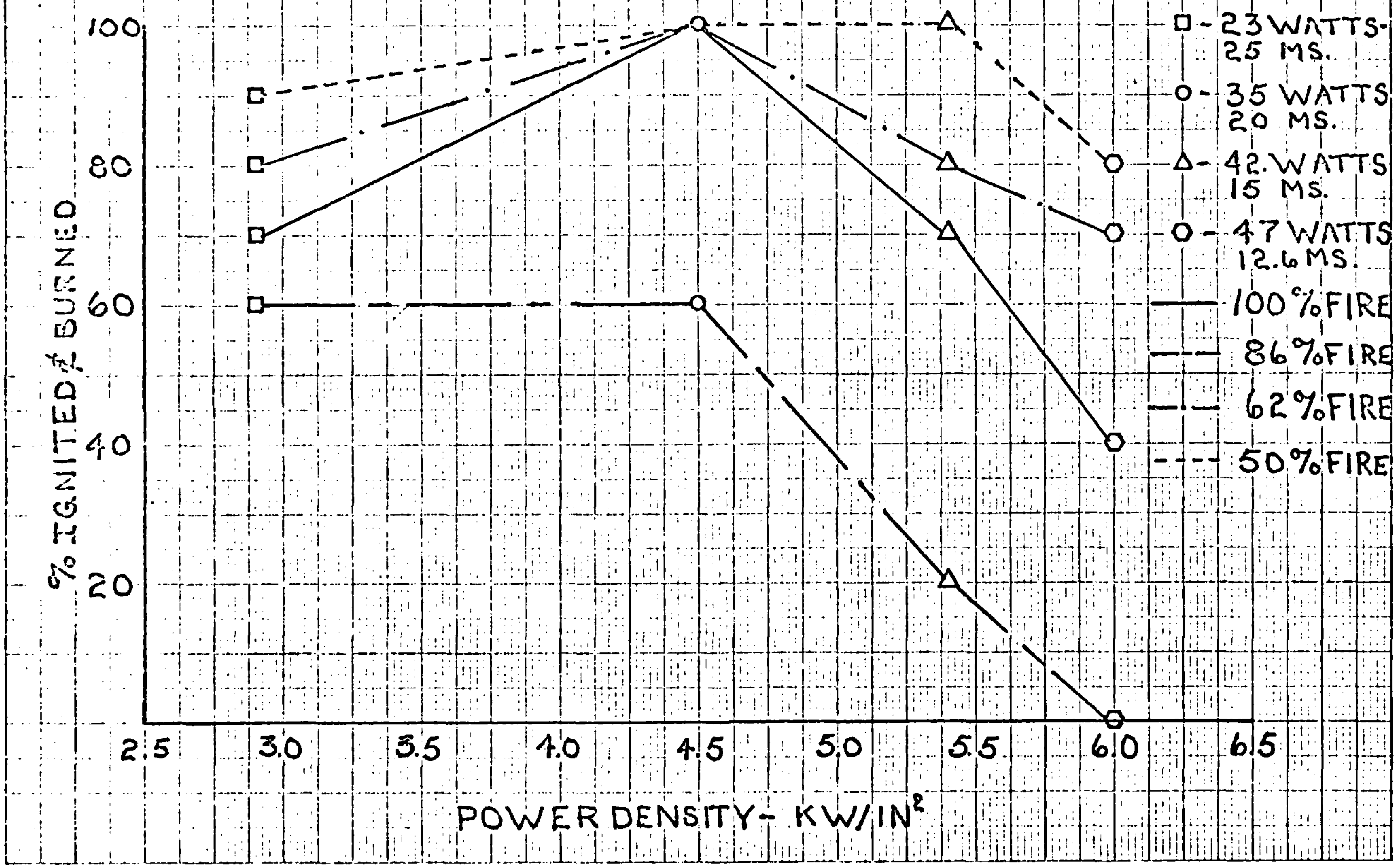
*NOTE: All energies are corrected for losses by reflection.

order to investigate a range of stimulus from zero to a 100% firing level. The effect of power density on laser ignition performance is shown in Figure 5 and its relationship to ignition time in Figure 6. Samples which performed well in a weapon were more sensitive to power density. That some critical spot temperature is needed to generate a self-sustaining exothermic reaction in the tracer material is evident. Establishment of this parameter for tracers is beyond the planned scope of this series of experiments although much work has been reported for other explosives[5].

4. Excessive power density is detrimental to laser ignition as shown in Figure 5. If tests #3 and #4 in Table IV are compared, it will be seen that for test #3 the power input was twice that of test #4 and the duration of stimulus less by one-half so that the overall energy input was effectively the same. However, the percent ignited and burned was less in all cases for the high power density and particularly so for those samples (86 and 100%) considered to be acceptable. Figure 7 illustrates this well. The

FIGURE 5

% IGNITED & BURNED VS. POWER DENSITY



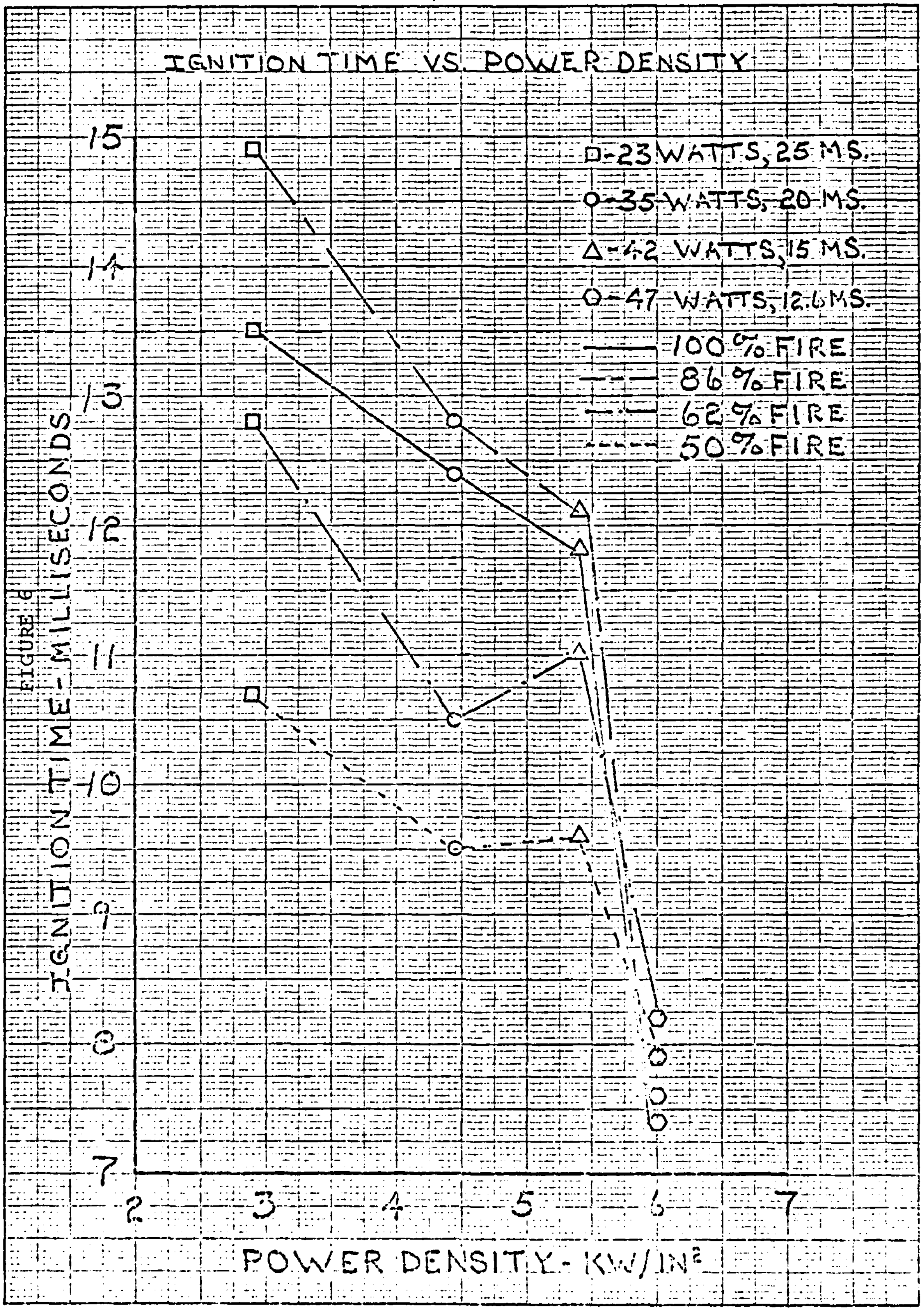
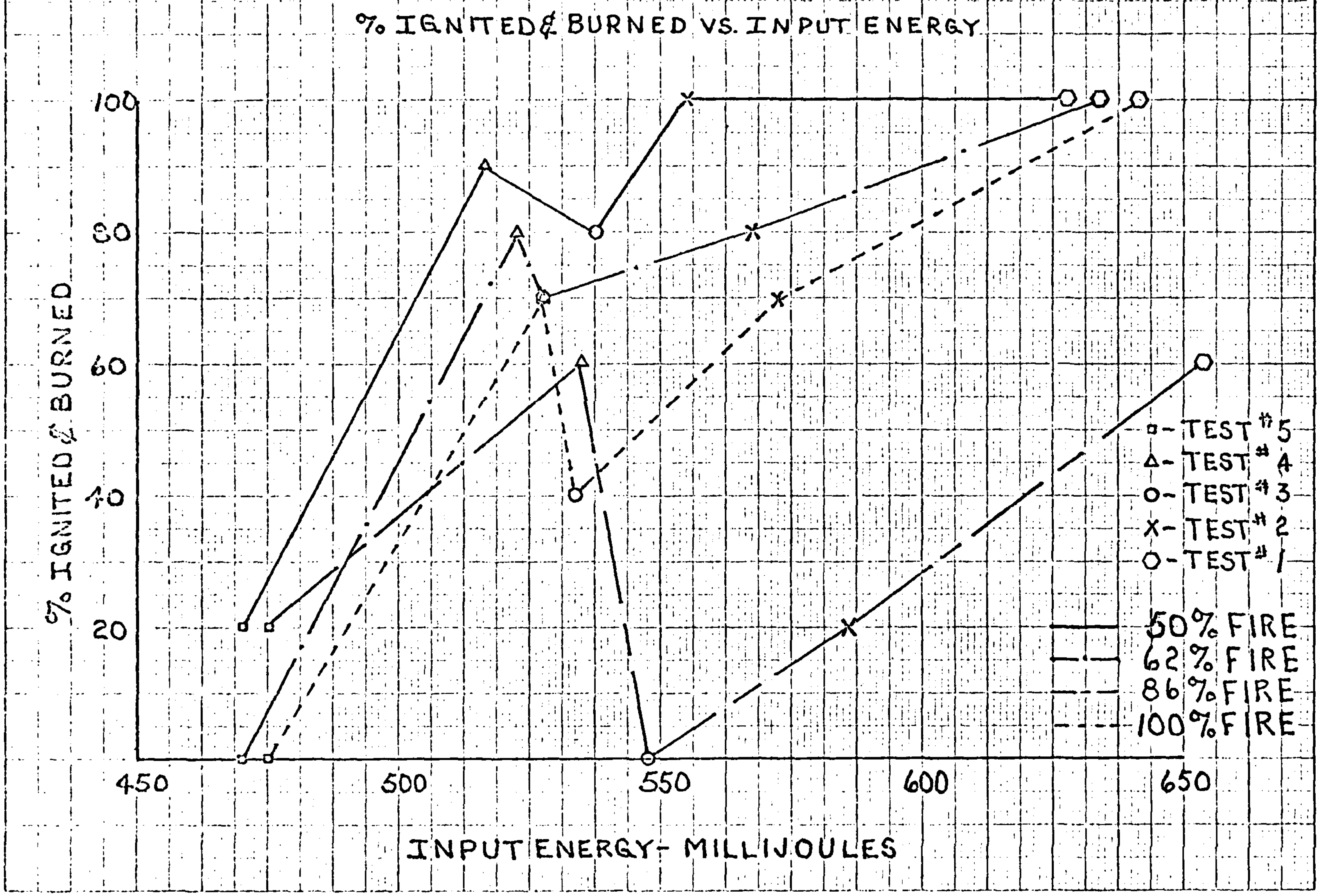

IGNITION TIME VS. POWER DENSITY
□-23 WATTS, 25 MS.
○-35 WATTS, 20 MS.
△-42 WATTS, 15 MS.
○-47 WATTS, 12.6 MS.
100% FIRE
86% FIRE
62% FIRE
50% FIRE
IGNITION TIME - MILLISECONDS
15
14
13
12
11
10
9
8
7
2
3
4
5
6
7
POWER DENSITY - KW/IN²

FIGURE 6

FIGURE 7



% IGNITED & BURNED VS. INPUT ENERGY
% IGNITED & BURNED
100
80
60
40
20
450
500
550
600
650
INPUT ENERGY- MILLIJOULES
□ - TEST # 5
Δ - TEST # 4
o - TEST # 3
X - TEST # 2
O - TEST # 1
50% FIRE
62% FIRE
86% FIRE
100% FIRE

breaks in all curves indicate that a loss of the energy available to the exothermic reaction has occurred. This can reasonably be attributed to changes of state in the tracer mixture or ejection of materials from the sample surface. Some evidence of both phenomena was found upon examination of those tracer bullet samples which were partially ignited.

5. The ignition and burn characteristics of the tracers varied widely as exemplified by the following observed reactions.

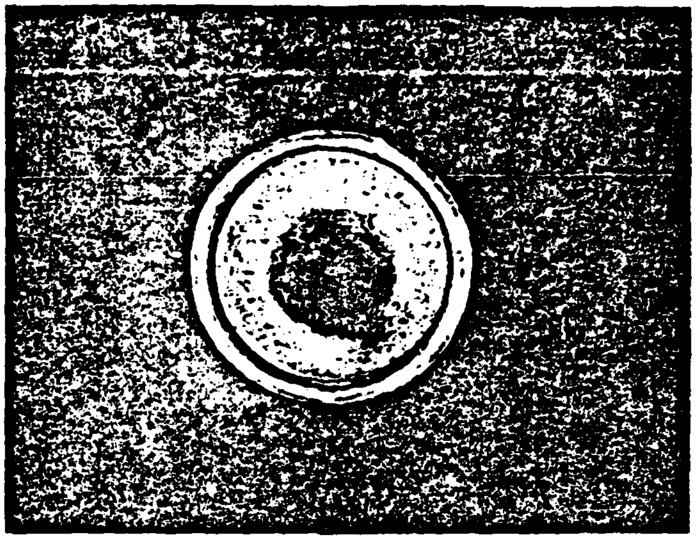
   a. Fire - good ignition and a complete burn

   b. Fire - short burn. The tracer mixture burns down to a certain level at which the remaining mass is ejected from the bullet casing with no additional burning

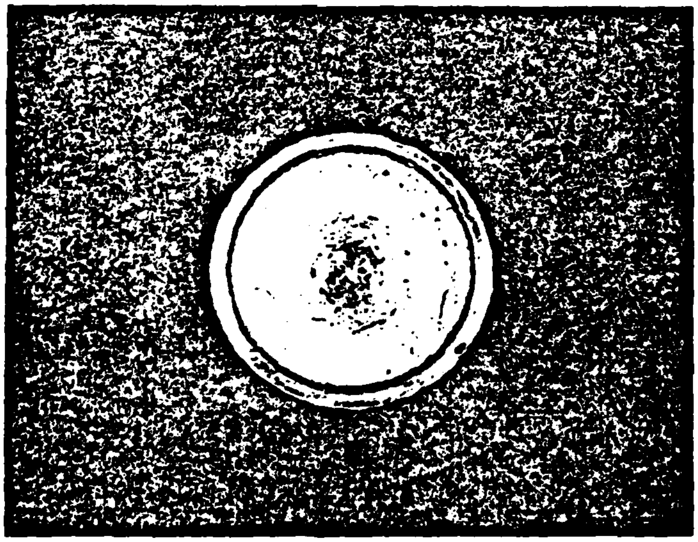
   c. Fire - erratic burn. The level of burning varies greatly and an intermittent cessation of radiant output occurs that could be due to the ejection of tracer material during the burn.

d. Partial Ignition - ignition of the igniter materials occurs as evidenced by erratic radiation of a duration longer than the laser pulse. However, no light output is detected by the photometer and apparently burning is taking place at a lower temperature. Examination of the tracers reveals a very definite indication of burning as evidenced by blackening of the walls of the tracer cavity, cratering at the bottom of the cavity, and the presence of slag as shown in the photograph (Figure 8).

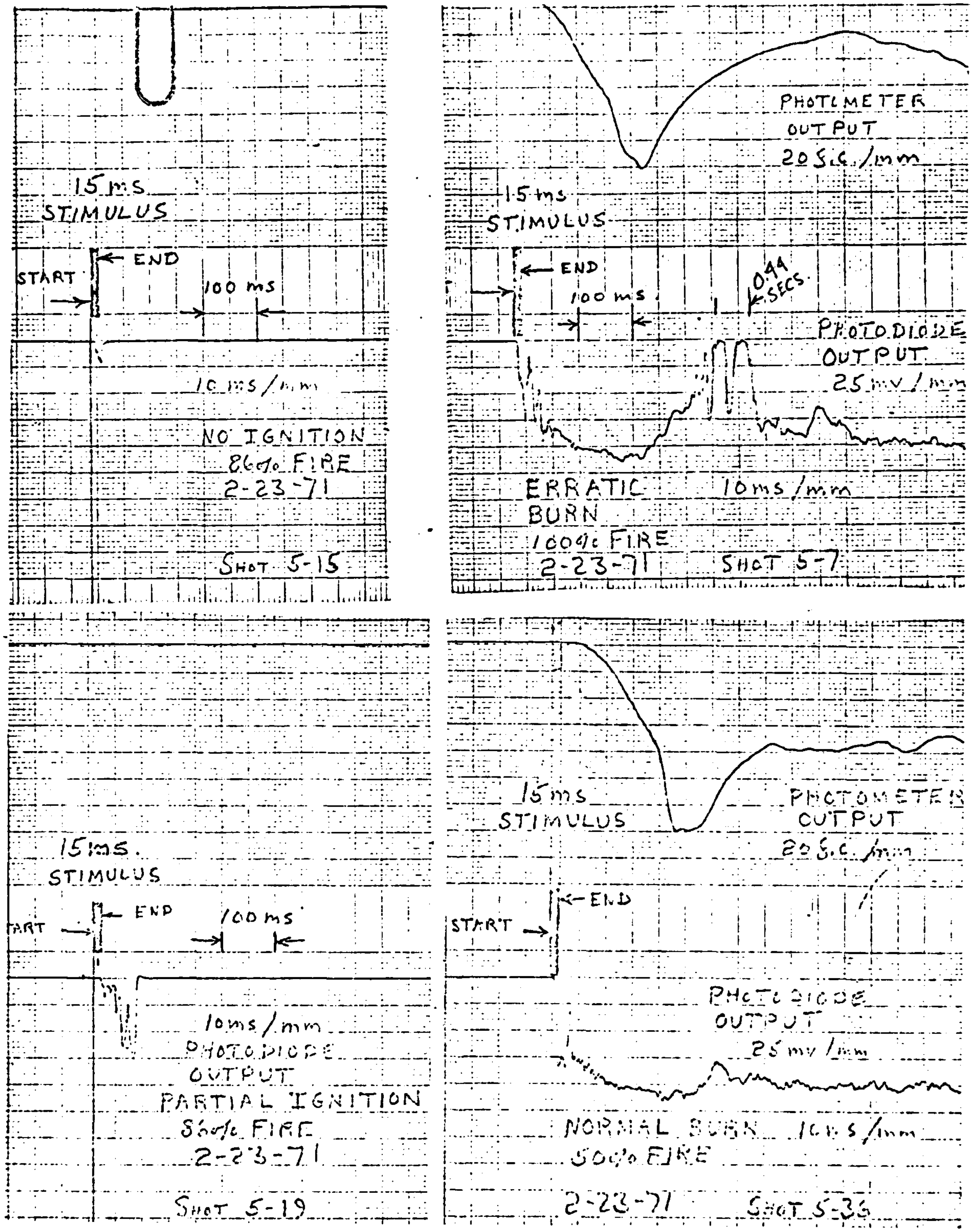
e. Ignition Failure - very little or no output radiation is detected, and when detected its duration is equal to or shorter than the applied laser stimulus. Examination of the tracer usually reveals scattered spots of localized activity and a small amount of slag. See Figure 9. Recorded outputs as taken on multichannel galvanometer recorder are shown in Figure 10 for the various conditions of ignition described.



PARTIAL IGNITION - 5.56mm TRACER
FIGURE 8



IGNITION FAILURE - 5.56mm TRACER
FIGURE 9



RECORDED PHOTOMETER & PHOTODIODE OUTPUTS FOR TYPICAL IGNITION AND BURN CONDITIONS

FIGURE 10

C. Reflective Properties of Samples Lots

It is logical to assume that the optical surface properties of the compacted tracer would vary depending upon the nature of the igniter material used, degree of tamping, condition of the tamping punch, etc.

Measurements of reflectance using a helium-neon laser source have found a difference between sample lots that is statistically reliable at a confidence level of 0.95. The most notable result was that the sample lot with the poorest weapon performance also has the greatest reflectance. Furthermore, the anomaly between the positions of the 86% and 100% samples previously noted for the laser ignition tests also is present for the reflectance measurements. The sample least reflective was the next best performer in a weapon firing test as shown in Table VI.

TABLE VI

Sample Reflectance

Sample	% Reflectance
100%	10.0
86%	8.3
62%	10.7
50%	11.2

IV. EXPERIMENTAL METHODS AND EQUIPMENT

1. Laser Beam Power Measurement and Control

A pictorial diagram (Figure 11) shows the general functional layout. Initially the continuous output beam from the CO_2 laser is blocked by a solenoid operated stainless steel reflector that directs the beam to a thermopile, the output of which is amplified and sent to a multi-channel galvanometer recorder. The first reflector acts as the opening gate, and a second solenoid operated reflector, initially clear of the beam path, serves as the closing gate for the laser beam. This shutter system is synchronized with a motor driven chopper disc which controls the duration of the laser stimulus. Synchronization is obtained by use of an electromagnetic pick-up which senses the passage of a magnetic disc fastened to the chopper blade surface. The output pulse from the pick-up is amplified, shaped, and directed to an operator controlled "fire" switch for shutter solenoid control. (See Figure 12). Output of the amplifier is also sent to an electronic counter which serves to measure and continuously monitor the aperture time generated by the chopper disc. The location of the magnetic disc on the chopper blade is set so that the shutter opening and closing operation is completed during the time the beam is cut off by the chopper blade. After passing through the chopper aperture, the beam is folded twice with

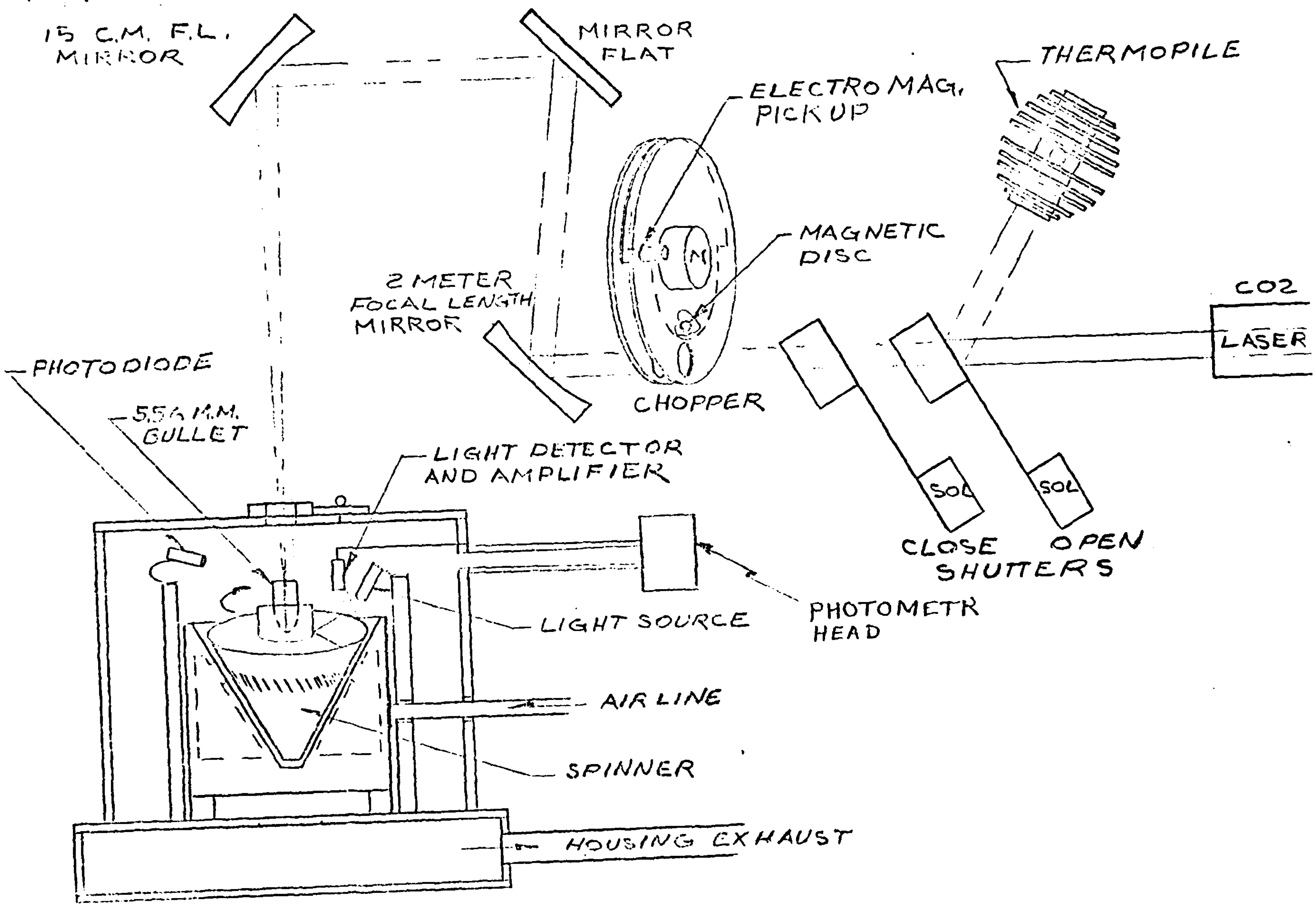

15 C.M. F.L. MIRROR
MIRROR FLAT
THERMOPILE
ELECTRO MAG. PICK UP
MAGNETIC DISC
CO2
LASER
2 METER FOCAL LENGTH MIRROR
PHOTODIODE
5.56 M.M. BULLET
CHOPPER
LIGHT DETECTOR AND AMPLIFIER
SOL
SOL
CLOSE
OPEN
SHUTTERS
PHOTOMETR HEAD
LIGHT SOURCE
AIR LINE
SPINNER
HOUSING EXHAUST

FIGURE 11

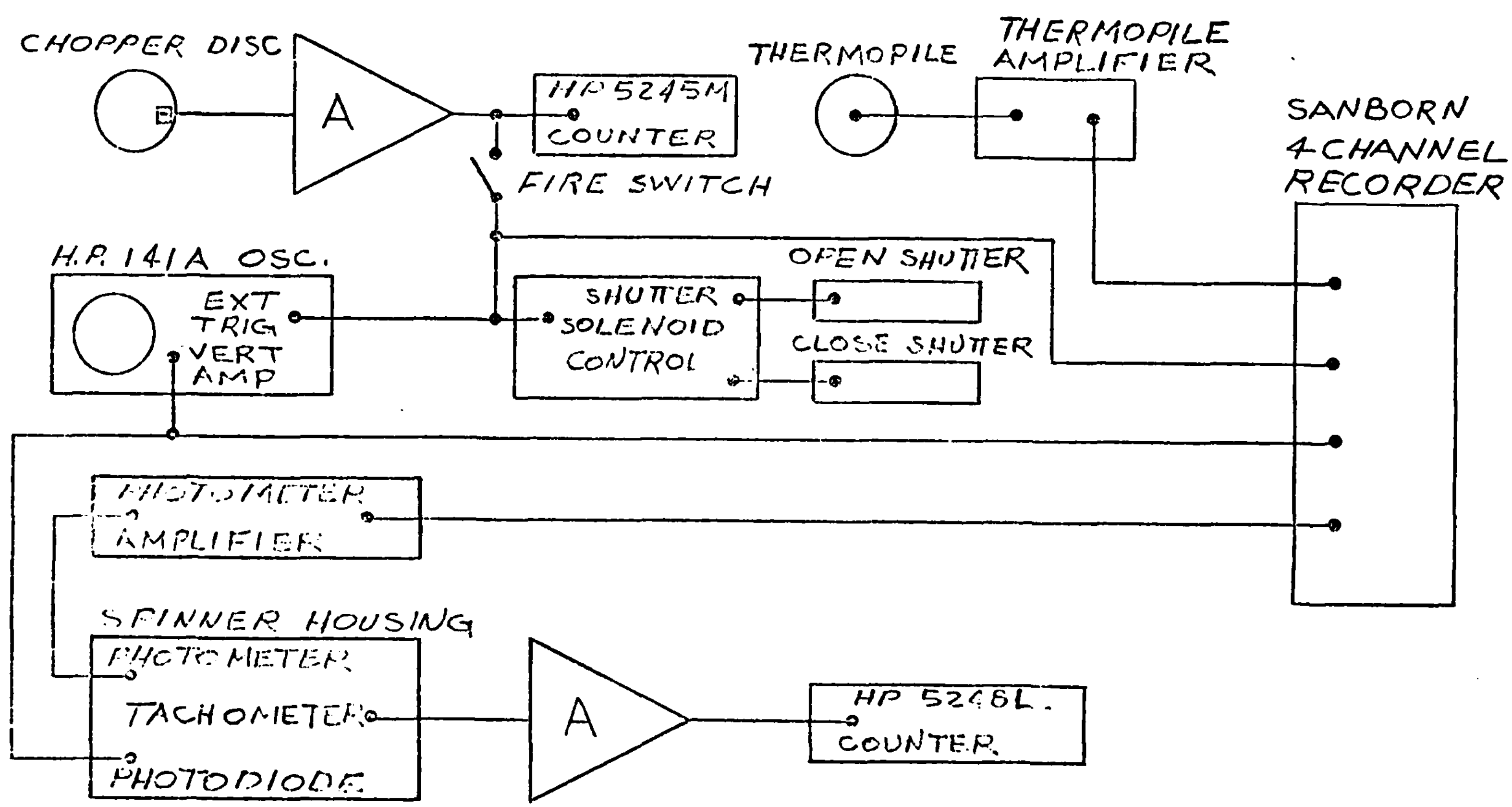
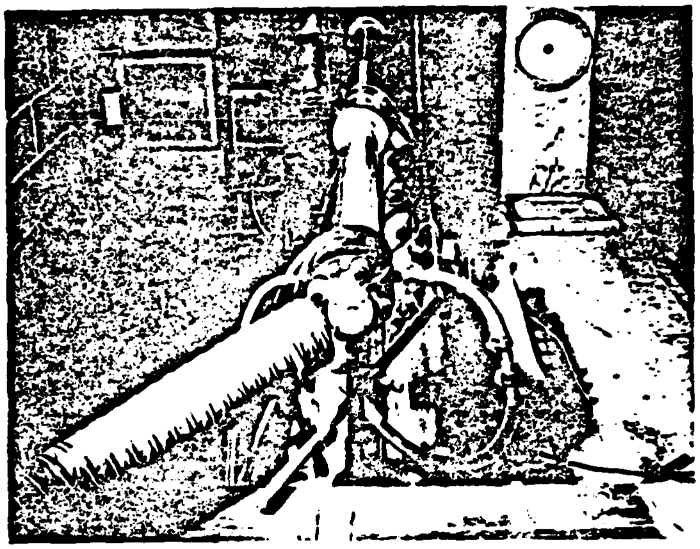

CHOPPER DISC
A
HP 5245M
COUNTER
FIRE SWITCH
THERMOPILE
THERMOPILE
AMPLIFIER
SANBORN
4-CHANNEL
RECORDER
H.P. 141A OSC.
EXT
TRIG
VERT
AMP
SHUTTER
SOLENOID
CONTROL
OPEN SHUTTER
CLOSE SHUTTER
PHOTOMETER
AMPLIFIER
SPINNER HOUSING
PHOTOMETER
TACHOMETER
PHOTODIODE
A
HP 5246L.
COUNTER

FIGURE 12

gold front surface flats and then focused by a gold front surface sherical mirror (15 cm. focal length) on to the bottom of the depression formed in the tracer material by the tamping punch. Distance of the mirror from the laser surface was set to produce an approximately 0.1" diameter spot that covers the bottom of the depression in the tracer. A photograph of the carbon dioxide gas laser as taken from the output end is shown in Figure 13 and a view of the spinner apparatus, mirrors, chopper, and thermopile shown in Figure 14 as seen from in back of the 15 cm. focusing mirror. The solenoid driven shutters are just noticeable to the right of the chopper.

2. Spinner RPM Measurement

The spinner provided by Frankford Arsenal is well described in Report R-1704[2]. A housing was built to contain the spinner both for safety reasons and to provide a means of containing and exhausting the combustion products from tracer burning. The housing was made from 12" O.D., - 3/8" wall, steam pipe. Mountings for the focusing mirror and the photometer were fastened to the side of the housing and the housing itself mounted on a rectangular wooden box which serves both as a base for the housing and a chamber for coupling to the vacuum cleaner exhaust system.



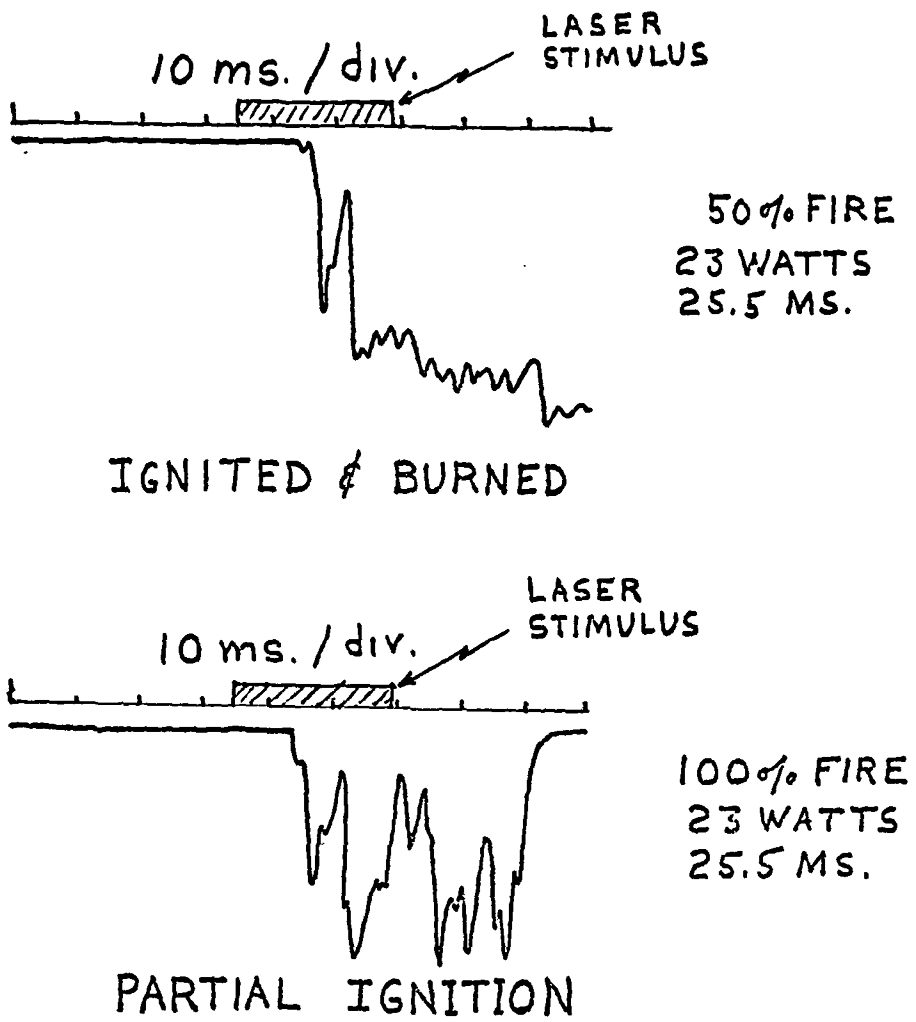
CARBON DIOXIDE GAS LASER
FIGURE 13

TRACER SPINNER & EXPERIMENTAL APPARATUS
FIGURE 14

To measure the spinner rotation rate, a flat black coating with a reflective gap was sprayed on the flat surface of the spinner cone. A tungsten filament light source and a photo field effect transistor detector are mounted and oriented so that passage of the reflecting gap increases the light flux into the detector. The output pulse from the detector is then amplified, shaped, and sent to an electronic counter for RPM measurement and readout.

3. Measurement of Ignition Time

Ignition time is measured directly from a storage oscilloscope display of the output of a photo-diode used to detect the radiant emmission from the tracer. A storage oscilloscope, retains, until erased, the information display generated by a single sweep of its electron beam at a known rate. The sweep is triggered by the first pulse from the electromagnetic pick-up following the closure of the firing switch. Time is measured from the start of the recorded trace to the first vertical deflection signal. Figure 15 is a typical scope display for both the partial ignition and normal ignition and burn conditions. The relative timing and duration of the applied 23 watt-25 millisecond stimulus has been added. Due to the initial pick-off position of the start signal for the scope sweep, it is necessary to calculate the true time on the following basis:



TYPICAL SCOPE DISPLAY

FIGURE 15

$$T_I = T_R - 1.33 \text{ (Blocking Aperture Time)}$$

where T_I = Ignition Time

T_R = Recorded Time

The aperture time is obtained from the electronic counter reading of time per revolution divided by two since the chopper disc used for all tests had a 180° blocking segment. A 1.33 factor compensates for the fact that a 60° lead exists due to the relative position of the electromagnetic pick-off. Although the initiating trigger does occur during the transmitting section of the chopper disc, the solenoids are too slow to respond in this time interval for the range of chopper speeds used and shutter transfer is restricted to the blocking time of the chopper disc.

4. <u>Relative Reflectance Measurements</u>

To check the relative amount of energy reflected from the tracer samples, a Model 120 Spectra Physics helium-neon laser was used. It has an output of approximately 9 milliwatts at a wavelength of 0.63 micrometers in the red portion of the visible spectrum. A special beam splitter mounting was designed to fit over the rotor of the bullet spinner so that measurements could be made with the same optical system used to direct and focus the CO_2 laser beam. Figure 16 is a drawing of the unit in position for testing. A front surface mirror, actually the polished end surface of an aluminum rod, was used in place of the

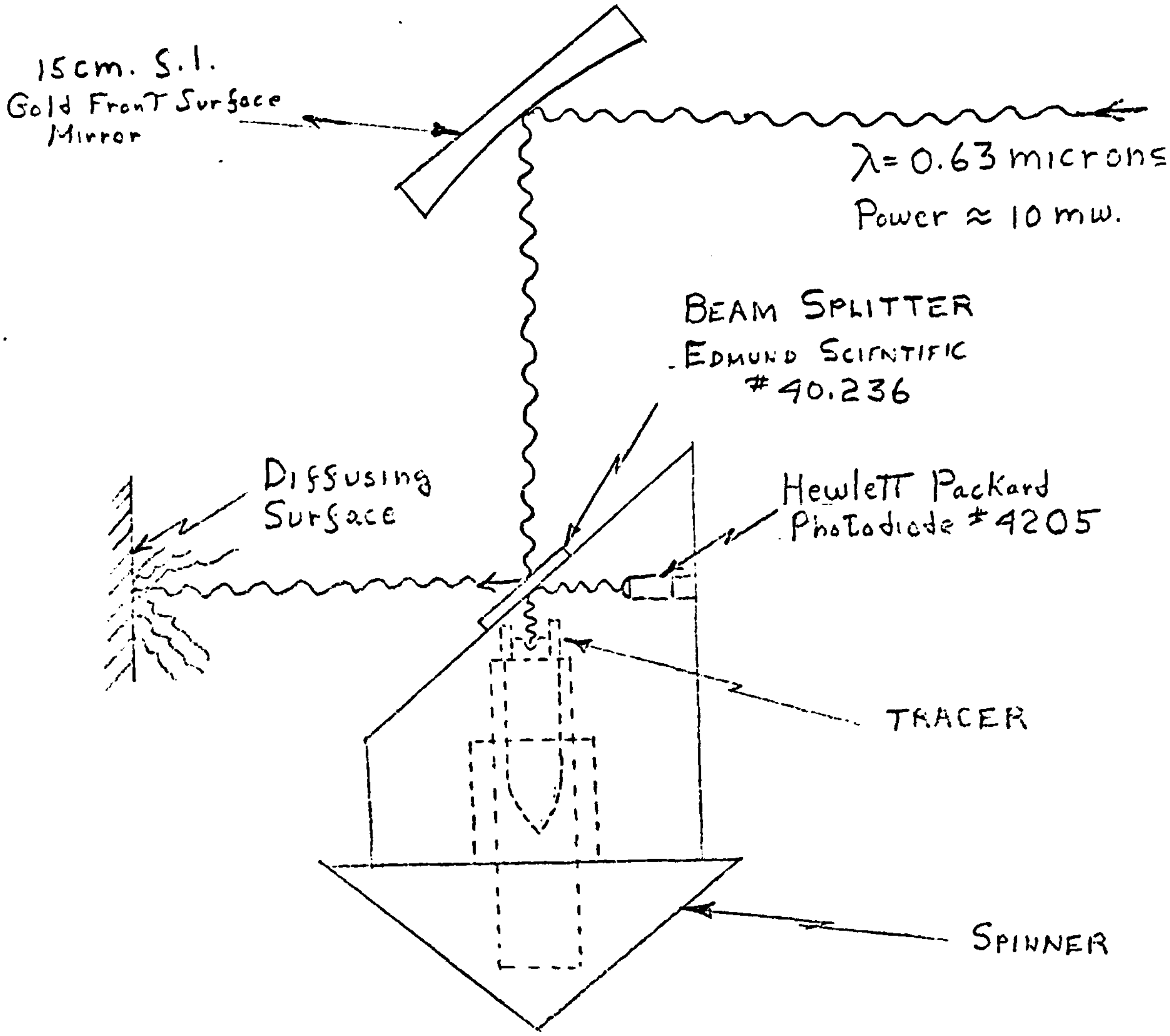

15cm. S.I.
Gold Front Surface
Mirror
λ= 0.63 microns
Power ≈ 10 mw.
BEAM SPLITTER
EDMUND SCIENTIFIC
#40.236
Diffusing
Surface
Hewlett Packard
Photodiode #4205
TRACER
SPINNER

FIGURE 16

tracer to obtain a value for the maximum reflected energy. Recorded values for the samples were expressed as a percentage of this maximum and a total of thirty bullets measured for each sample. The laser beam was gated through the chopper system and the amplitude of the output pulse from the photo-diode detector displayed on an oscilloscope for measurement of the relative light outputs. A diffusing target was used to trap the light off the back surface of the beam-splitter in order to prevent feedback of light to the photo-diode.

5. Laser Beam Characteristics

The carbon dioxide gas laser used as a source of infrared energy was designed and built at Remington Arms Company, Inc. It is two meters in length and emits a continuous collimated infrared beam at a wavelength of 10.6 micrometers. Operation is multimode and unstabilized which means that all modes of oscillation are allowed to propogate within the laser cavity. This results in a beam with a non-uniform and changing intensity distribution transverse to its direction of propagation. Therefore, the power densities given in this report are average and hot spots of considerably greater intensity do occur within the beam cross section.

6. Light Output Detection and Measurements

a. Photometric Measurements

A Gamma Scientific Model 700 log-linear photometer with a Model 700-4 cosine receptor head was used to measure the tracer light output. Recording of the photometer output was made on a multi-channel galvanometer recorder. The cosine receptor head contains a photoptic filter to provide the standard luminosity curve of the human eye for footcandle measurements. With this head the sensitivity varies with the cosine of the angle the incident ray makes with a line normal to its receiving surface. Distance of the receiving surface from the burning tracer was set at 12 inches and the receiving angle limited by a 1" aperture placed 3-1/4" from the cosine receptor surface. Response of the photometer was too slow to allow integration of the light output signal from the tracer bullet to be performed on the recorded curve. Since only burning duration and relative output measurements were needed, this limitation presented no difficulty.

b. Radiometeric Measurement

A Model 4205 Hewlett-Packard PIN photo-diode served as a detector of the radiant output of the burning tracer. This photo-diode has a spectral response curve extending into the near-infrared at 1.1 micrometers so that it picked up radiant emission from the tracer before light output started. One advantage in using the CO_2 laser as a source is that the detectors are blind to the la r's 10.6 micrometer wavelength and therefore only the effects of the stimulating source are detected. The photo-diode was mounted on the rim of the spinner housing and looks at the tracer from above at an angle of approximately 15° and from a distance of 3" to the end of the tracer bullet.

V. DISCUSSION

Differences between sample lots of tracer bullets have been found by experiment. The differences are in the reflective properties, ignition energies, and the fraction successfully ignited and burned at various laser stimulus levels. No correlation was found between reported weapon firing performance and laser ignition performance (% ignited and burned). However, the differences in reflectance and ignition energy between sample lots indicate these factors are worthy of investigation as possible indicators of lot quality. Both reflective and ignitive properties of the tracer bullets can be expected to relate to the surface characteristics of the tamped igniter and sub-igniter mixtures. Surface characteristics in turn will be functions of tamping pressure, tool condition, and the amount, composition, and condition of the tracer mixtures; all of which are factors subject to control before the final crimping and closure operation. Sample differences for ignition energy were not found for all tests, but the results do indicate that differences will be found over a limited range of radiant power density at the sample surface. High power densities obscure the differences due to alteration of the surface characteristics by changes of state or material ejection at the sample surface. Low power densities and longer stimulus times introduce sub-surface properties such as thermal diffusivity that wouldn't normally be considered for the very short duration transient pressures and temperatures generated in a gun chamber during firing. Examination of test results indicates that a CO_2 laser power of 42 watts, a pulse duration of 15 milliseconds, and a spot diameter of approximately 0.100" (effective diameter because of contoured shape of punch indentation) would provide a suitable input for further investigation. Statistical analysis indicated a 0.99 confidence level for rejecting the null hypothesis of no difference between samples at this stimulus level. While a proposal has been submitted for additional work using a neodymium-glass laser, the use of a CO_2 laser is advantageous for the first step in a new testing program.

VI. RECOMMENDATIONS

From random samples of production lots of tracer bullets:

1. Make relative reflectance measurements at 6328A with a Helium-Neon Laser.
2. Make ignition energy measurements using a CO_2 laser.
3. On the basis of 1 and 2 predict weapon performance.
4. Make weapon firing tests on all samples.
   a. For those samples measured for reflectance, complete the manufacturing operation. Identify the samples by their relative reflectance and determine if differences can be established both within and between samples.
   b. For those sample lots, portions of which were destroyed by ignition energy measurement, assume that the balance of the sample is representative of the quality of the lot.
5. Examine test results. If no correlation is found, it will have to be assumed that there are overriding factors that invalidate the differences in surface quality, such as;
   a. Impact sensitivity
   b. Pressure - peak or rate or rise in firing

c. Temperature - peak or rate of rise in firing

d. Powder burning rate

e. Crimping operation

f. Closure

g. Primer energy

h. Weapon condition

i. Environmental effects

A combination of any or all of these factors, since some are definitely interrelated, could be responsible for poor performance.

It is known for instance that the following corrective actions have succeeded in salvaging lots classified as unacceptable.

a. Addition of new igniter material

b. Recrimping-this apparently breaks up the igniter surface.

c. Change of propellant

The effect of transient firing pressure on the ignition of tracers would appear to be the next most promising parameter for investigation. A combination of laser stimulus with confinement of the tracer equivalent to that in a weapon, and the incorporation of additional static or transient pressures would provide additional information on the ignition process.

At this point, the neodymium glass laser would be used as the source for practical reasons. Confinement will necessarily require transmission of laser radiation through the confining means and ordinary optical materials will not transmit the CO_2 laser's 10.6 micron wavelength. Other forms of stimuli such as impact, adiabatic compression of a confined gas, etc. would be logical areas for additional experimentation.

6. If test results indicate a correlation between weapon firing and either reflectance or ignition energy or both, then an investigation to determine the effects produced by variations in tamping pressure and mixture quality will be needed to designate those factors of greatest importance for quality control.

VII. REFERENCES

(1,2,3) T. Stevenson, "Tracer Bullet Ignition", Frankford Arsenal, Philadelphia, Pa.

(4) T. A. Doris & W. W. Cavell, Report R-1704, U.S. Army - Frankford Arsenal, Philadelphia, Pa. "Laboratory Simulation of Tracer Functioning" January 1964.

(5) Bowden & Yoffe, "Initiation and Growth of Explosion in Liquids and Solids", Pgs., 64-65, Cambridge University Press, 1952.

END

DATE
FILMED
1-82

DTIC